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Paper for DCCAE

FTTH technology, market adoption and suitability for the NBP

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1 Executive summary

This paper has been developed by Analysys Mason as part of our technical support to the National Broadband Plan (NBP) team at the Department of Communications, Climate Action & Environment (DCCAE).

Main objective of this paper is to provide independent advice to DCCAE regarding the following questions:

- What are the global trends relating to operator choice for FTTH deployment?
- What are the strengths and weaknesses of competing FTTH technology choices?
- Why an operator may or may not consider XGS-PON[1] versus other FTTH technologies?
- What is the 'future proofness' of XGS-PON technology over 25 years?
- How suitable would be XGS-PON as a technology for choice for the purposes of the NBP?

Global trends relating to operator choice for FTTH deployment

Since 2006, GPON has been the fundamental building block for the vast majority of FTTH deployments outside Asia, and it is increasingly complementing or superseding EPON in Asian markets.

At the end of 2017 FTTH networks passed about 700 million premises worldwide, or 31% of all premises in the world. Total installed port capacity of all FTTH operators was for about 1.25 billion lines. Of these about 60-65% were GPON, the rest mostly EPON. The total number of active GPON lines stood at about half of the 400 million active FTTH lines. (The fact that this implies a higher conversion-rate on non-GPON is simply a result of Chinese incumbent operator policy to migrate DSL lines to EPON based FTTH.)

In Western Europe, of the estimated installed port capacity for 77 million FTTH subscriber lines at YE 2017, about 90% was on GPON, the rest being mostly PTP. By the same date, GPON had been deployed by one - or in some regions more than one - FTTH operator to pass a total of 51 million premises, or about 25% of all premises in Western Europe. At YE2017 there were about 15.3 million active GPON lines, about 81% of the total FTTH.

Strengths and weaknesses of competing FTTH technology choices

As more operators enter the market, an increasing number are trialling, and in some cases deploying, GPON successor technologies such as XG-, XGS- and TWDM-PON. GPON is the most mature technology standard and is also the cheapest to deploy. XGS-PON, which can accommodate 4 times the GPON download bandwidth and 8 times the GPON upload bandwidth, remains more expensive

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[1] See definition of XGS PON in Section 3.3.2 of this paper

to deploy than GPON[2], but is gathering significant momentum from operators worldwide which will see its cost fall significantly in the next two to three of years due to high anticipated volumes. TWDM-PON can currently offer 4 times the capacity of XGS-PON but needs to mature as a technology for a wider adoption by operators for the residential mass market. TWDM is currently an order of magnitude more expensive than GPON.

Future Proofness XGS-PON technology over 25 years

The all-encompassing full-service network vision of the FSAN group consists in creating a utility network (i.e. the PON network) which can provide a full range of services over the same physical infrastructure. The (N)G-PON standards largely reflect this position as the different NG-PON technologies (including XGS-PON) are defined to co-exist on the same physical PON network. This ensures that the physical PON network is a future proof platform and can accommodate NG-PON overlays without having to modify the infrastructure network, this in turn, protects operators 'Investment in the PON infrastructure for the next 25 years and beyond.

Why operators may or may not consider XGS-PON versus other FTTH technologies

A number of operators worldwide have already deployed NG-PON technology overlay for different reasons:

- Large Incumbent such as China Telecom, China Mobile, KDDI and AT&T[3] have all deployed XGS-PON overlays.
- Verizon, who has longer-term capex and opex avoidance aims, and who places greater emphasis on enterprise and mobile transport opportunities, have deployed the less mature but higher specification TWDM-PON.
- Altice, itself a vendor of PON equipment, is committed to TWDM-PON overlay as a replacement for cable in the USA. Altice also supplies its subsidiary operator businesses in Portugal and France.
- Very few operators have launched NG-PON at scale in Europe other than Salt in Switzerland, who entered the broadband market in March 2018 using XGS-PON technology and with a 10Gbit/s symmetrical broadband service retailing at less than half of the price of competitors' 1Gbit/s services.

In Ireland, open eir and Siro are both deploying GPON-based FTTH networks, and it is anticipated that, due to increasing competition between themselves and with Virgin Media, NG-PON overlay will be deployed within the next 3 years in Ireland. Siro have already signalled that it has successfully trialled XGS-PON in December 2017, in partnership with Huawei. Eir, recently acquired by the same owner as Salt may also deploy XGS-PON.

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[2] XGS-PON are 2 to 5 times more expensive than GPON-ONT

[3] Due to launch is Q1 2018

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Other key drivers pushing operators to deploy NG-PON networks include providing symmetrical multi-gigabit business connectivity, providing backhaul for wireline broadband networks as well as providing backhaul and fronthaul connectivity services for cell densification and 5G.

It seems likely that by mid 2020s, 1Gbit/s services will be sold to some consumers and small businesses, and that in regions with competitive telecoms many, perhaps most, operators will also sell multi-gigabit access. However, any operator going straight to any form of NG-PON now would have carefully to balance the higher up-front active equipment costs now against the longer asset-life of a higher-capacity network.

Suitability and future proofness of XGS-PON as a technology for deployment in the NBP

Based on the Government objectives associated with the NBP, we believe that:

- XGS-PON will enable NBPco not only to meet but also to exceed the Government objective in terms of broadband speedfor all active "Minimum Required Wholesale Products", including bitstream and VUA.
- Fibre Unbundling Products could be provided by means of TWDM-PON overlays from Service Providers on NBPco PON network, but the economics is unlikely to work in rural Ireland.
- XGS-PON may be able to provide some form of virtual Fibre Unbundling in the medium term through network slicing technology.
- Considering its symmetrical profile, XGS-PON will be particularly suitable to provide services to businesses and Strategic Connection Points.
- XGS-PON should enable NBPco to provide Wholesale Products with similar characteristics to those provided in commercial area until late 2020's.
- PON will provide a future proof platform and NBPCo will have an upgrade path in terms of technology till the end of the contract.

Although XGS-PON attracts a cost premium compared to GPON today, using XGS-PON will not significantly impact the cost per premises to pass[4] and will only increase the cost to connect by ▇▇▇ ▇▇▇ (if XGS-PON costs were to remain as they are today). However, as XGS-PON volumes increase, we expect XGS-PON costs to continue falling in the foreseeable future which will partially compensate for the premium to pay for premises which will be connected in the early years of the NBP deployment. Also, deploying XGS-PON straight at the beginning of the contract period will enable NBPco to refresh active at a much later stage than if GPON was deployed (i.e. refreshment in late 2020's with XGS-PON instead of the mid 2020's for GPON), leading to capex avoidance, a reason which has been put forward by Verizon to deploy NG-PON technology[5].

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[4] We consider OLT costs as cost to pass in our Budget model

[5] although Verizon deployed TWDM-PON rather XGS-PON

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2   Introduction

This paper has been developed by Analysys Mason as part of our technical support to the National Broadband Plan (NBP) team at the Department of Communications, Climate Action & Environment (DCCAE).

Main objective of this paper is to provide independent advice to DCCAE regarding the following questions:

- What are the global trends relating to operator choice for FTTH deployment?
- What are the strengths and weaknesses of competing FTTH technology choices?
- Why an operator may or may not consider XGS-PON[6] versus other FTTH technologies?
- What is the 'future proofness' of XGS-PON technology over 25 years?
- How suitable would be XGS-PON as a technology for choice for the purposes of the NBP?

To answer the above questions, we have structured this paper as follows:

- Section 2 summarises the different FTTH technologies available including the latest roadmap, compares the relative strength and weaknesses of the competing GPON technologies, and explains how the different generations of NG-PON can co-exist on the same network to ensure operators investment is future proof.

- Section 3 provides a view of the global NG-PON market illustrated by examples of recent trials and launches of different NG-PON technologies, explaining the rational for the adoption for next generation PON technologies and, providing a forecast of the number of the number of ports for the different NG PON technologies.

- Section 4 discusses the suitability of XGS-PON technology for the NBP network.

- Section 5 concludes this paper.

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[6] See definition of XGS PON in Section 3 3 2 of this paper

3 FTTH technology options and roadmap

3.1 Introduction

Fibre to The Home (FTTH) is increasingly becoming a viable alternative to copper, coaxial and fixed wireless networks to provide high speed broadband services to end-users as, at the end of year 2017, FTTH networks passed about 700 million premises worldwide, or 31% of all premises in the world.

Operators have several options to implement FTTH networks both in terms of physical topologies and technology, and their decision is based on their own market conditions and the type of services they want to provide.

In this section, we provide an introduction to FTTH topology options, provide a technology roadmap for the most popular FTTH technology (i.e. GPON technology family as issued by the standardisation body FSAN), compare the strength and weaknesses of the latest generations of GPON technology family, and explain how different NG-PON technologies can co-exist on the same PON as overlay networks to provide a future proof platform.

3.2 FTTH topologies

Operators wanting to deploy an FTTH network have two options for physical topology:

- passive optical network (PON) topology
- point-to-point (PTP) topology.

Below we describe these in more detail.

3.2.1 Passive optical network (PON) architecture

A passive optical network (PON) is a point-to-multipoint, FTTH-based architecture, in which un-powered (passive) optical splitters are used to enable a single optical fibre to serve a number of subscribers (typically 32 or 64). Other PON components include the optical line terminal (OLT) at the infrastructure provider's local exchange and optical network terminals (ONTs) located with the end users. These components are illustrated in Figure 3.1.

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Figure 3.1: Typical PON architecture [Source: Analysys Mason, 2018]
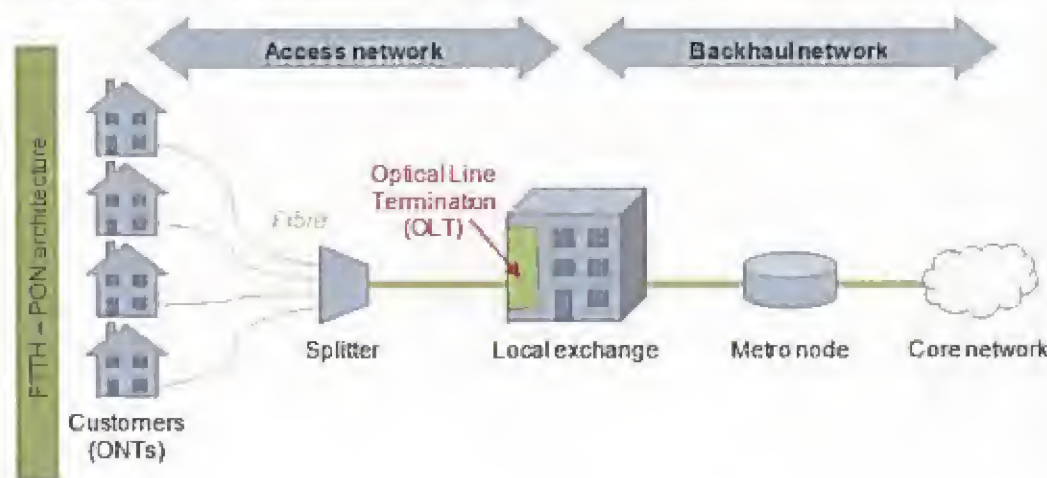
In a PON, the single fibre between the OLT and the passive splitter is shared by all customers connected to the PON, significantly reducing the requirements on the number of fibres in the network.

The active layer is defined as all electronic components in the network. There are two principal options for implementing the active layer for PON:

- **Ethernet PON (EPON)** is an IEEE/EFM standard for using Ethernet in the last mile standard (IEEE 802.3ah). EPON is applicable for data-centric networks, as well as full-service voice, data and video networks. EPON is less popular in Europe and in the USA than in China, Japan and South Korea where it dominates. Hence, since this report is designed for the NBP in Ireland, we concentrate on GPON technology.

- **Gigabit PON (GPON)** is an evolution of the Broadband PON (BPON) standard and its standardisation is supported by the International Telecommunications Union (ITU) and the Full-Service Access Network (FSAN[7]) Group. GPON is the most popular PON technology in the US and in Europe.

3.2.2 Point-to-point (PTP) architecture

PTP architecture is based on Ethernet technology and usually implemented by means of a dedicated fibre with dedicated capacity between the local exchange and each individual end-user premises. This is illustrated in Figure 3.2.

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[7] FSAN is not a Standards Development Organization (SDO) in itself but bring a technical contribution to the standards. It is composed of telecom operators, equipment manufacturers, chip vendors and device manufacturers including China Telecom, China Unicom and other major global telecom operators and Huawei, ZTE, Fiberhome and other major global equipment manufacturers, as well as Mitsubishi, Macom, Marvell, Finisar, Hisense, Broadcom and other major devices and chip manufacturers.

Figure 3.2: Typical Point-to-Point Architecture [Source: Analysys Mason, 2018]
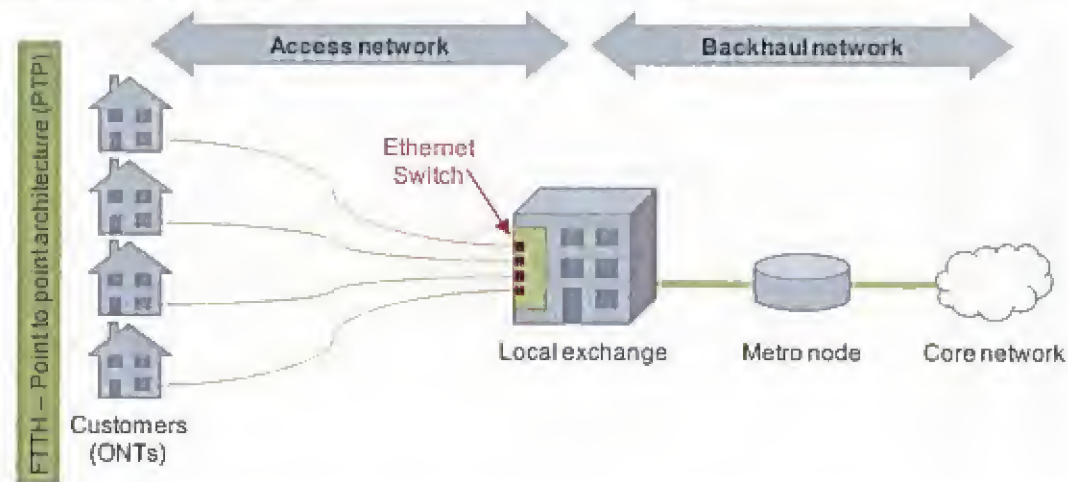
Since in excess of 90% of operators who have deployed FTTH networks have deployed a PON based network in Europe, we concentrate on GPON technology in the rest of this paper.

3.3 PON technology roadmap

In order to guide the development of existing and future PON technology standards, the FSAN Group[8] has set out a PON technology roadmap in December 2016. This roadmap is illustrated in Figure 3.3.

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[8] FSAN is not a Standards Development Organization (SDO) in itself but bring a technical contribution to the standards

Figure 3.3: FSAN Standards Roadmap 2.0 [Source: FSAN, DEC 2016]
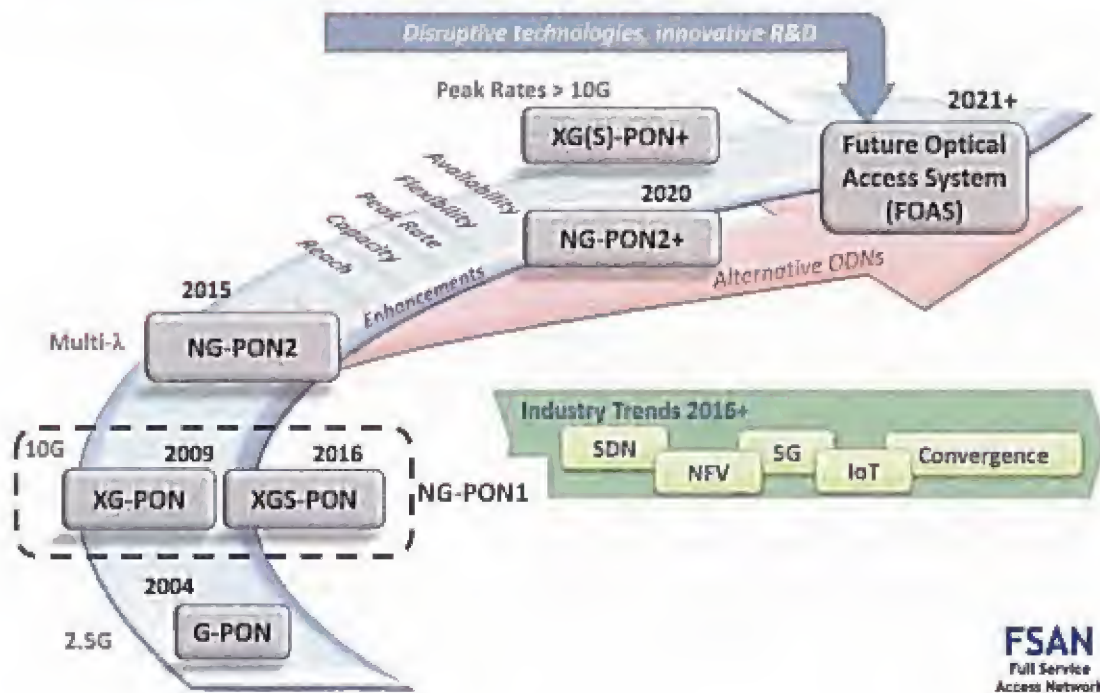
In the above figure, there are five main GPON/NGPON technology families:

- GPON
- Next generation PON 1 (NG-PON1);
- Next generation PON 2 (NG-PON2);
- XG(S)-PON+ and NG-PON2+ and;
- Future Optical Access System (FOAS).

We describe the main characteristics of each of these technologies below.

3.3.1 GPON

GPON technology is by far the most common technology deployed in PON networks outside of China, Japan and South Korea. GPON was standardised in 2004 by the ITU-T (G.984 standards) and can provide 2.5Gbit/s of bandwidth in the downstream direction and 1.25Gbit/s of bandwidth in the upstream direction. As a PON based technology, the downstream and upstream bandwidths are both shared between all users connected to the PON. Interestingly, two Chinese operators (China Telecom and China mobile) have started to deploy the latest generation of GPON as an overlay to

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their existing EPON network. This will contribute to driving volume for the GPON technology family.

3.3.2 NG-PON 1

NG-PON1 standards essentially includes two different NG-PON technologies:

- XG-PON and;
- XGS-PON.

We describer each of these technologies below.

Ten Gigabit PON (XG-PON[9]) was standardised (ITU G.987) in 2009 and can provide an asymmetrical bandwidth of 10Gbit/s downstream and 2.5Gbit/s upstream. XG-PON is essentially a higher bandwidth version of GPON. It has the same capabilities as GPON and can co-exist on the same fibre with GPON. XG-PON has been trialled and commercially deployed by a small number of operators prior to 2017 as evidenced in Section 4.2 of this paper.

Recognising the limitations of the asymmetrical profile of XG-PON, **Ten Gigabit Symmetrical PON (XGS-PON)** was standardised under ITU G.9807.1 in 2016. XGS-PON provides 10Gbit/s of bandwidth for both the upstream and the downstream. XGS-PON can also co-exist with GPON on the same PON but cannot co-exist with XG-PON[10]. XGS-PON is being trialled and commercially deployed and has gathered some momentum amongst operators as evidenced in Section 4.2 of this paper.

3.3.3 NG PON2

NG-PON2 standards essentially includes two different NG-PON technologies:

- Time-Wavelength Division Multiplexing (TWDM) PON
- Wavelength Division Multiplexing (WDM) PON

TWDM-PON[11] was standardised as part of the NG-PON2 standards under ITU G.989 in 2015. Characterised by flexible bit rate wavelengths[12], TWDM-PON can provide the equivalent of **up to four[13]** XG-PON or four XGS-PON[14] overlay systems within a single PON network. This is illustrated for a four XG-PON overlay system in Figure 3.7, where the four 10Gbit/s downstream overlay signals are transmitted on wavelengths λ_1 to λ_4 and the four 2.5Gbit/s upstream overlay

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[9] The 'X' in XG-PON stands for the number 10.

[10] XG-PON and XGS-PON share the same downstream spectrum as illustrated in Figure 3.6.

[11] TWDM PON is part of the NG-PON 2 family.

[12] TWDM PON wavelength can either be 2.5Gbit/s or 10Gbit/s

[13] G.989.2 fully standardises TWDM PON for 4 wavelengths but the full standardisation of 8 wavelength systems is for further work. However G.989.2 already allocates up to 8 wavelengths in each direction for TWDM-PON.

[14] or a mix of XG-PON and XGS-PON

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signals are transmitted on wavelengths λ_5 to λ_8. To get the full benefits of wavelength mobility[15], tuneable lasers are required in TWDM-PON systems. As discussed in Section Figure 3.3, TWDM-PON can co-exist with GPON, and XG-PON or XGS-PON. Also, TWDM-PON is particularly suited to Fibre Unbundling as different RSPs can each deploy a TWDM-PON wavelength on the Wholesaler PON network, a technique that is specifically identified in the State Aid Guidelines[16] to provide Fibre Unbundling in PON networks.

Among major operators, only Verizon (USA) and Altice (USA with operations in Portugal and France) have started deploying TWDM-PON in any volume, as explained in Section 4.2, and but it remains too expensive to be widely adopted for the residential mass market in the short to medium term.

WDM-PON was also standardised as part of the NG PON2 in 2015. WDM-PON consists in allocating a dedicated wavelength to every end-user on the PON, effectively providing them with a logical point-to-point connection. WDM-PON currently typically provides a dedicated 1Gbit/s of symmetrical bandwidth to each connect end-user. WDM-PON can be used in two different configurations:

- *Configuration 1*: using the traditional power splitter where each end-user receives all the wavelengths and the ONT has to filter out the wavelength which is destined for a particular end user

- *Configuration 2*: with a WDM multiplexer to demultiplex the wavelengths and only transmit the appropriate wavelength to the appropriate end-user.

Configuration 2 is not compatible with existing PON deployments as it would involve the replacement of the power splitter by a WDM multiplexer/demultiplexer. Therefore, WDM-PON can only be deployed as a greenfield network or as a major overhaul of an existing network. However, Configuration 2 benefits from an extended reach compared to Configuration 1. This is because a WDM multiplexer will typically exhibit a loss of less than 2dB but a 1:32 power splitter will typically exhibit an attenuation in excess of 16dB. This 14dB difference is equivalent to the attenuation of 56km of fibre[24], allowing WDM-PON to have an extended reach while deployed in Configuration 2.

Irrespective of the configuration chosen, WDM-PON requires tuneable lasers, making it expensive to deploy in mass residential markets and more suited to high bandwidth business end-user market.

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[15] Wavelength mobility refers to the ability of dynamically turning on or off particular wavelengths, switch across wavelengths, or logically bonding wavelengths together

[16] See Article 78 (d) of EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks, EC, 2013

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3.3.4 XG(S) PON+ and NG-PON2+

XG(S)-PON+ and NG-PON2+ will essentially be enhancements to existing XG(S)-PON and NG-PON2.

Increasing the line rate speed from 10Gbit/s to 25Gbit/s and beyond is the first enhancement that FSAN/ITU are focusing on. To determine the optimum speed to be standardised, FSAN/ITU are conducting a cost benefit analysis considering different speeds such as 25 Gbit/s, 50Gbit/s or 100Gbit/s. They are also considering more technical factors such as new modulation schemes, impact on link budgets and many other issues. A key focus remains to make the technology cost effective for mass market adoption.

Definition of 5G Fronthaul[17] requirements in a PON context is another enhancement that FSAN/ITU are considering as part of the XG(S) PON+ and NG-PON2+.

Other areas of focus for the FSAN/ITU includes the application of Software Defined Networks (SDN) and Network Function Virtualisation (NFV) to the GPON roadmap. For example, ONT may become virtual CPE which means that its functionality will be delivered by software rather than dedicated hardware. This means that operators will be able to implement new functionalities on the CPE such as network performance monitoring.

3.3.5 Future optical access systems (FOAS)

FOAs are still at an early research stage and we do not have any specific details regarding the type of technologies which will be considered.

3.4 Comparison of PON technology

In order to assess the relative strengths and weaknesses of the different NG-PON technologies, we compare upstream/downstream speed, optical budget, reach, maturity of technology and cost of ONT on Figure 3.4.

Figure 3.4: Comparison between PON technologies [Source: Analysys Mason, 2018]

	GPON	XG-PON	XGS-PON	TWDM-PON	WDM-PON	XG(S) PON+
Downstream peak rate (Gbit/s)	2.5	10	10	n^{18} x 10	k^{19} x 1	25 40 100

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[17] Fronthaul is usually defined as the network connecting Remote Antennas of 5G systems back to the processing Baseband Broadband units.

[18] n between 1 and 8. Current commercial TWDM systems have 4 wavelengths (i.e. n=4) and standards have allocated up to 8 wavelengths

[19] K between 1 and 40. Each of the 40-connected end-user would get a dedicated 1 Gbit/s.

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	GPON	XG-PON	XGS-PON	TWDM-PON	WDM-PON	XG(S) PON+
Upstream peak rate (Gbit/s)	1.25	2.5	10	$n^{19} \times 2.5$ $n^{19} \times 10$	$k \times 1$	25 40 100
Optical budget (dB)	28-32	31	31	29-35	29-43	?
Reach (km)	<20	<20	<20	<25	20 to 60	unknown
Standardised	Yes	Yes	Yes	Yes	Yes	No
Technology maturity	+++++[20]	++++	+++	++	+++	+
ONT cost (USD)	40	80-120	100-200	200-800[21]	>500	?

3.4.1 Optical budget comparison

Different classes of lasers have been standardised for the different NG-PON Technology. We provide in Figure 3.5 standardised link budgets for the different NG-PON technologies.

Figure 3.5: Link budget for different PON technologies [Source: Analysys Mason, 2018]

Laser classes	B+/N1	C+/N2	E1	E2
GPON link budget (dB)	28	32	N/A	N/A
XG(S)-PON (dB)	29	31	N/A	N/A
TWDM-PON link budget (dB)	29	31	33	35

It can be seen that all PON technologies have at least 31dB of link budget. Moreover, TWDM-PON has E1 and E2 classes of lasers which can extend the link budget to 33 and 35dB respectively. A key consideration when developing NG PON standards was that operator should be able to deploy NG-PON technology in existing PON networks[22] (e.g. with a similar link budget to GPON).

E1 and E2 laser classes were standardised to overcome the additional loss incurred by the TWDM WDM multiplexer demultiplexer and by the co-existence element. However, it should be noted that TWDM-PON E1 and E2 class lasers are currently significantly more expensive to manufacture than their N1 and N2 counterparts, but the industry is investigating how these could be reduced by using alternative components.

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[20] Five "+" indicates that the technology is very mature and one "+" indicates that the technology is still at the research stage

[21] Fixed wavelength TWDM-PON tend to be at the lower end of the scale and tuneable wavelength TWDM-PON tend to be at the higher end of the spectrum

[22] Which have been deployed using GPON link budget

3.4.2 Reach comparison

Reach is largely dependent on the link budget, fibre attenuation at the operating wavelength and the number of splits in the PON network. Typically, longer reach can be obtained by decreasing the number of splits in PON networks. For example, using a 1:8 split instead of a 1:32 split will add an additional 6dB in the link budget, equivalent to an additional 17km[23] of fibres for and XGS-PON or 24km[24] for a TWDM-PON system. However, a reduction in the number of splits means that more OLT ports are required to be installed in the network for the same number of end-users, as each PON port serves a smaller number of end-users.

As mentioned in Section 3.3.3, WDM-PON used in Configuration 2 has a significant longer reach than any other PON technologies. However, WDM-PON can cannot co-exist with any other (N)G-PON technology if deployed using Configuration 2, which does not make it future proof.

TWDM-PON has a slightly better reach than GPON and XG(S)-PON technologies. This is mainly because the upstream spectrum band associated with the TWDM-PON is higher than any other technology and therefore is subject to less attenuation in the fibre as explained in Section Figure 3.6.

3.4.3 Technology maturity comparison

In terms of maturity, GPON has been commercially deployed since 2006 and represents the vast majority of FTTH ports deployed worldwide.

XG-PON had been deployed by a few operators at scale but is now obsolescent in favour of its symmetrical counterpart XGS-PON. XGS-PON is developing into maturity as, since 2017, a significant number of operators have adopted the technology and we do not see this trend to slow down for some time. As illustrated in Section 4.2, since 2017 large incumbent operators such as China Telecom, China Mobile, KDDI, Telefonica Spain and AT&T have all started to deploy, or are committed to deploying, XGS-PON.

TWDM-PON is less mature than XGS-PON as there are still technical issues to be resolved to ensure that its cost is compatible with residential mass market price points. However, with both Verizon and Altice commercially deploying the technology, we believe it is going to become a mature technology within the next 3 years.

WDM-PON is more mature than TWDM-PON because equipment vendors have been providing proprietary WDM solution since 2008 for operators purely focussing on the business market (e.g. Unet in the Netherland).

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[23] Assuming a fibre attenuation of 0.35dB/km in the 1260nm spectrum band

[24] Assuming a fibre attenuation of 0.25dB/km in the 1550nm spectrum band

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3.4.4 ONT cost comparison

We use the ONT as a proxy to compare the cost associated with different (N)G-PON technologies.

Large volumes of GPON equipment have been deployed since 2006 which means that GPON equipment has benefited from a significant cost erosion ever since. Today the typical cost of a GPON ONT is less than USD40.

The asymmetrical downstream and upstream profile of XG-PON was largely motivated by the objective of providing a GPON upgrade for the mass residential market with a cost-effective ONT. This is because, XG-PON does not require any 10Gbit/s laser transmitter in the ONT[25], which at the time was a significant driver of cost. However, since XG-PON is becoming an obsolescent technology, the cost trends are less relevant.

Driven by the rapid proliferation of data centres in the past 5 years, 10Gbit/s optics have become a commodity and their cost has significantly eroded. This is because a large volume of 10Gbit/s interfaces are required in data centres to interconnect different network components. Today, XGS-PON ONT we believe that the cost of a XGS PON ONT is between USD100 and USD200. Given the adoption of the XGS-PON technology, we believe that the price of ONTs will continue to decrease and will be below USD100 within the next 2 years. Full interoperability between different vendors' ONT and OLT is a requirement for increasing vendor competition and therefore reduce the costs of a particular generation of PON. A major "plugfest"[26] for XG-PON and XGS-PON equipment was conducted in France in November 2017 which will contribute to further reducing the cost of XGS-PON ONTs.

To obtain full benefits, TWDM-PON relies on tuneable lasers, whose reliability comes at a price currently too high for the residential mass-market. Today, we believe that the cost of TWDM-PON ONTs are typically between USD200 and USD800, depending on whether it is a fixed or tuneable wavelength TWDM-PON system. The NG-PON2 Forum, in which Verizon is the leading player, seeks to drive down component prices, increase interoperability and ultimately push low-cost-high-volume adoption of TWDM-PON.

3.5 Co-existence of different PON technologies and upgrade path

3.5.1 Standardised GPON spectrum

The all-encompassing full-service network vision of the FSAN group consists in creating a utility network (i.e. the PON network) which can provide a full range of services over the same physical infrastructure. The (N)G-PON standards largely reflect this position as they are defined to co-exist on the same physical PON network. This is achieved by allocating different frequency bands to different NG-PON technologies so that they can be multiplexed together into the same fibre without

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[25] In XG PON, only a 2.5Gbit/s transmitter and a 10Gbit/s receiver (photodetector) is required

[26] A plugfest is an inter-operability test- see https://www.fsan.org/industrys-first-xgs-pon-plugfest-extends-pon-interoperability/

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interfering with each other. The standardised spectrum[27] used by each (N)G-PON technology is illustrated in Figure 3.6 below:

Figure 3.6: Spectrum used by NG-PON technologies [Source: adapted from ITU-T[27], 2018]
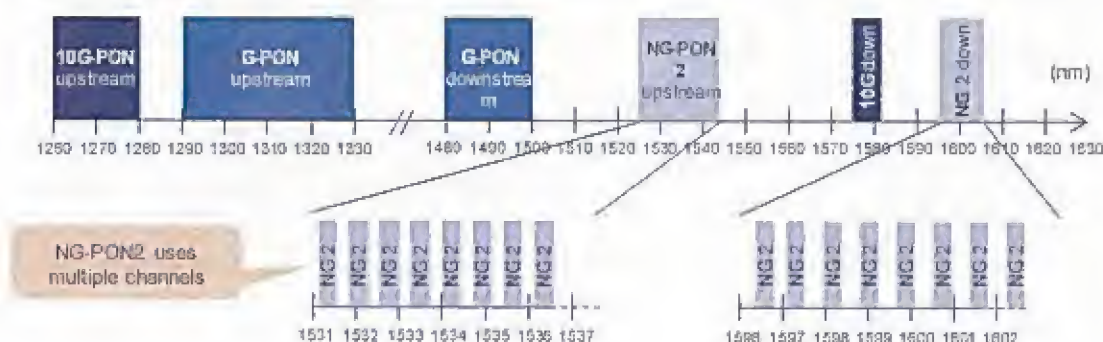
NG-PON2 standards allocates enough spectrum for TWDM-PON to accommodate up to 8 different wavelengths for both upstream and downstream, enabling up to 8x10Gbit/s upstream and downstream capacity to be shared between end-users connected to a PON. To multiplex/demultiplex all wavelengths associated with TWDM-PON, a WDM multiplexer/demultiplexer is integrated as part of the TWDM-PON system.

Also, since the fibre attenuation is wavelength dependent (the lower the wavelength, the higher the attenuation), NG-PON2 is the technology which will incur the lowest fibre attenuation because the frequency band allocated for its upstream transmission path has the highest wavelength of all GPON technologies (in terms of upstream frequency). Therefore, the reach of NG-PON2 technology is slightly higher than the reach of other NG-PON technologies (see Section 3.4.2).

3.5.2 Co-existence of GPON technology

For different NG-PON technologies to co-exist on the same PON network, a co-existence element is required to multiplex the different wavelengths into the same fibre. The co-existence is implemented as a WDM multiplexer. Figure 3.7 illustrates a PON network with different (N)G-PON overlay, clearly identifying the role of the co-existence element.

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[27] See ITU-T G 989.2 40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification, Appendix 1

Figure 3.7: Example of aggregation of different PON technologies on the same PON network [Source: Analysys Mason, 2018]
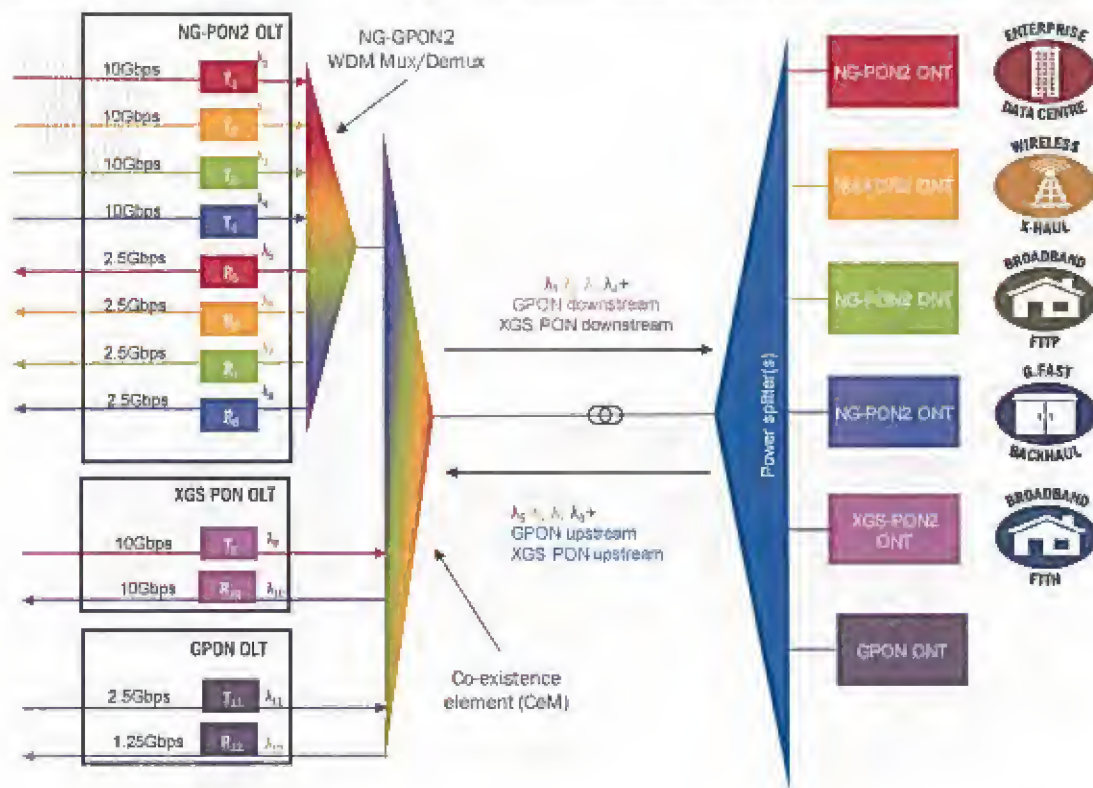
It should be noted that, in future generations of GPON (e.g. XGS-PON+ / NG-PON2+), the co-existence element will be integrated as part of the line card, and therefore it will not be a separate element in the PON system which needs to be installed on day one.

The ability of the different PON technology to co-exist means that operator does not have to perform any forced migrations of end-users from the "legacy" PON technology (e.g. GPON) to next generation PON technology (e.g. XGS-PON). Instead, the migration can be planned over several years, allowing different end-users to be connected to different (N)G-PON overlays. This also means that, when operators introduce a new NG-PON overlay, the operator does not have to replace all the ONT simultaneously as "legacy end-users" can continue using the "legacy" systems with their existing ONT. We discuss the upgrade path options in the next section.

3.5.3 GPON upgrade path options

Outside parts of Asia, most operators building FTTH have deployed GPON technology. The active GPON equipment costs represent only a small portion (typically 20% and often less) of total FTTH capex in developed economies; the passive fibre network and the support physical infrastructure account for the rest. Next-generation PON technologies are overlays, and represent an additional active equipment cost (new OLTs and new ONTs), but involve no change to the passive fibre network protecting operator's investment.

There are essentially three main options for PON upgrade for operators:

- Option 1: GPON to XG-PON
- Option 2: GPON to XGS-PON
- Option 3: GPON to TWDM-PON

These options are illustrated in Figure 3.8.

Figure 3.8: PON technology upgrade options [Source: Analysys Mason, 2018]
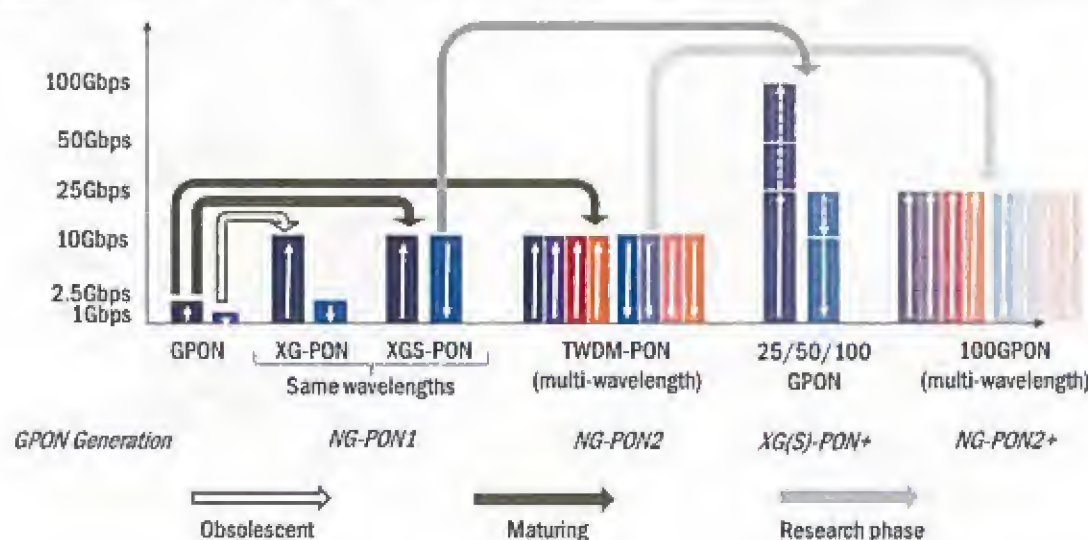
Up until Q1 2016, Option 1 was quite popular amongst operators as highlighted in Section 4.2 (see Figure 4.1). However, since XG-PON is now considered as an obsolescent technology, Option 1 upgrade has been superseded with Option 2 or Option 3. Option 2 is currently particularly popular mainly due to the cost reasons as Option 3 is more costly).

In addition, vendors and academics are researching the next possible upgrade paths beyond the standardised NG-PON variants (i.e NG(S)-PON+ and NG-PON2+). These include upgrade to asymmetrical and symmetrical 25Gbit/s to 100Gbit/s on fixed wavelengths and multi-wavelength (TWDM) equivalents with aggregate downlink of 100Gbit/s.

In any case, we believe that there will be an upgrade path for the foreseeable future in PON networks as future proofness is a key consideration by ITU/FSAN when developing GPON standards and associated roadmaps.

3.6 Conclusion

GPON is currently the prevalent FTTH technology worldwide with an estimated 200 million lines worldwide. GPON benefits from the global standardisation body (ITU-T) which standardises the technology and who works in close collaboration with the FSAN industry group to publish the 5-

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year GPON technology roadmap. This is an effort to provide more certainty for operators who currently invest in this technology to provide high speed broadband services.

Today, there are effectively six different GPON technology generations which have been commercially deployed including GPON, XG-PON, XGS-PON, TWDM-PON and WDM PON[28]. However, XG-PON is fast becoming obsolescent in favour of the symmetrical XGS-PON and WDM-PON is exclusively reserved for the business market due to its high cost. Therefore, the only feasible (n)G-GPON technology options for the residential mass market are:

- GPON;
- XGS-PON and;
- Potentially TWDM-PON.

GPON is the most mature technology standard and is also the lowest cost to deploy. XGS-PON, which can accommodate 4 times the GPON download bandwidth and 8 times the GPON upload bandwidth, remains significantly more expensive to deploy than GPON[29], but is gathering significant momentum from operators worldwide which will see its cost fall significantly in the next couple of years due to high anticipated volumes. TWDM-PON can currently offer 4 times the capacity of XGS-PON but needs to mature as a technology for a wider adoption by operators for the residential mass market. TWDM is currently an order of magnitude more expensive than GPON.

GPON technology and associated standards have been developed to ensure that different technology generations (e.g. GPON, XGS-PON and TWDM-PON) can all co-exist on the same PON network as they each use different wavelengths.

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[28] TWDM-PON and WDM-PON are part of the NG-PON 2 family

[29] XGS-PON are 2 to 5 times more expensive than GPON-ONT

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4 Global GPON technology adoptions and market trends

4.1 Introduction

GPON has been the fundamental building block for the vast majority of FTTH deployments outside Asia, and it is increasingly complementing or superseding EPON in Asian markets. As more operators enter the market, an increasing number is trialling, and in some cases deploying, the successor technologies XG-, XGS- and TWDM-PON.

At the end of 2017 FTTH networks passed about 700 million premises worldwide, or 31% of all premises in the world. Total installed port capacity of all FTTH operators was for about 1.25 billion lines. Of these we estimate about 60-65% were GPON, the rest mostly EPON. The total number of active GPON lines stood at about half of the 400 million active FTTH lines. (The fact that this implies a higher conversion-rate on non-GPON is simply a result of Chinese incumbent operator policy to migrate DSL lines to EPON based FTTH.)

In Western Europe, of the estimated installed port capacity for 77 million FTTH subscriber lines at YE 2017, about 90% was on GPON, the rest being mostly PTP. By the same date, GPON had been deployed by one - or in some regions more than one - FTTH operator to pass a total of 51 million premises, or about 25% of all premises in Western Europe. AT YE2017 there were about 15.3 million active GPON lines, about 81% of the total FTTH.

To better understand GPON technology adoptions and market trends, we consider the following:

- Trials and launches of different NG-PON technologies worldwide
- GPON deployment and trials in Ireland
- Rationale for adoption of NG-PONs

We explore the above issues in the following three sections.

4.2 Trials and launches of different NG-PON technologies worldwide

Although the capacity of GPONs is greater than other broadband technologies (such as xDSL and cable technologies) and sufficient for most needs for several years, some operators have seen a need for long-term planning as bandwidth demand rises. In addition, some markets have competing FTTH networks, so some have perceived a need to differentiate by upgrading PONs. The first upgrade options for GPON was XG-PON. However, after a series of trials, there were only a few launches of XG-PON, and these were confined mainly to the Developed Asia Pacific (DVAP) region. Initially multi-gigabit services were sold at a very high premium and take-up was very low, although some operators reported that being able to offer multi-gigabit services was a useful marketing tool and a differentiator. In addition, few end-user devices actually had the capability of benefitting from the speed, and there was little interest from businesses.

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As mentioned before, one perceived drawback of XG-PON was lack of upstream bandwidth, which makes it less flexible for non-consumer services and for backhaul use-cases. Since early 2017, there seems to have been a shift away from asymmetric XG-PON, and towards trials, and in a few cases commercial launches, of XGS-PON and TWDM-PON. Examples of commercial deployment and trials of XG-PON, XGS-PON and TWDM-PON are illustrated in Figure 1.

Figure 4.1: Trials and launches of NG-PONs October 2012 to present

Date	Operator	XG-PON (asymmetric)	XGS-PON (symmetrical)	TWDM-PON	Vendor (where known)
Oct-12	BT (Superfast Cornwall)	Trial			ZTE
Apr-13	So-net (Japan)	Launch[30]			Huawei
Mar-14	Etisalat			Trial	Huawei
Jan-15	KDDI	Launch			
Mar-15	NTT			Trial	In-house and OKI
May-15	Singtel	Trial			
May-15	Enecom (Japan)		Deployment		
Jul-15	Vodafone Spain			Trial	Nokia
Sep-15	M1 (Singapore)	Launch			
Sep-15	HKT	Launch			Huawei
Oct-15	Orange Spain	Trial			ZTE
Feb-16	Singtel	Launch			
Apr-16	Orange France	Trial			
May-16	Etisalat	Launch			Huawei
Jun-16	Verizon			Trial	Calix, Adtran
Aug-16	Orange Poland	Trial			Nokia
Oct-16	BT		Trial	Trial	Huawei
Oct-16	SK Broadband		Trial	Trial	Nokia
Dec-16	Telefonica Spain		Trial		Nokia
Dec-16	du (UAE)			Trial	Nokia
Dec-16	Altice USA			Deployment	Altice Labs
Feb-17	MGTS/MTS (Moscow)	Trial			Nokia
Mar-17	Ooredoo Qatar		Launch		Nokia
Apr-17	Elisa (Finland)		Trial		Nokia
Apr-17	NBN	Trial	Trial	Trial	Nokia
Jun-17	China Telecom		Deployment		Huawei, ZTE
Jun-17	China Mobile		Deployment		Huawei, Nokia
Aug-17	CenturyLink (USA)		Trial		Adtran
Dec-17	SIRO		Trial		Huawei

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[30] "Launch" refers to commercial launch (when a commercial service is available) whereas "Deployment" refers to the physical deployment of the network

Date	Operator	XG-PON (asymmetric)	XGS-PON (symmetrical)	TWDM-PON	Vendor (where known)
Jan-18	AT&T		Trial		
Jan-18	Verizon			Deployment	Calix, Adtran
Feb-18	SFR (France)			Trial	Altice Labs
Mar-18	Salt (Switzerland)		Launch		
Apr-18	KDDI		Launch		Zhone
2018	Telefonica Spain		Deployment		
2018	AT&T		Deployment		

Today there is significant movement to adopt next-generation PONs, but commitment is still patchy. China Telecom started major 10G EPON overlay in 2015, and both China Telecom and China Mobile started XGS-PON overlays in 2017. Outside China, US operators are in the driving seat because of their scale. Of the three large wireline telcos in the USA, AT&T (by far the largest) and CenturyLink appear lined up behind XGS-PON whereas Verizon is lined up behind TWDM-PON. Verizon deployment of TWDM-PON started in 1Q 2018 and we expect AT&T to start deploying XGS-PON in 2018. Most other operator groups worldwide, if they have any preference, are behind the simpler XGS-PON option. The only other significant operator grouping heavily committed to NG-PON2 is Altice, which is committed to GPON plus NG-PON2 as a replacement for cable in the USA. Altice is itself a vendor of PON equipment, supplying its subsidiary operator businesses in Portugal, France and the USA.

4.3 GPON deployment and trials in Ireland

Currently, open eir and Siro are deploying a network based GPON technology in commercial areas in Ireland. Enet have also announced that they will deploy GPON for 115,000 premises in commercial areas. We provide more details on these deployments below.

Eir deployment

In early 2017, Eir committed to extend their NGA footprint in Ireland by rolling out FTTH to 300,000 not served by FTTC. To date, eir have passed 145,000 premises and it is likely that it will be mid 2019 before eir will have deployed its FTTH network to the target 300,000 premises.

Eir's FTTH deployment is based on GPON technology. We understand that eir's new owners propose to concentrate on urban areas which are currently served utilising FTTC technologies. If eir were to upgrade from FTTC to FTTH in Dublin and other urban areas it is likely that they would deploy more that GPON to ensure a step change from their existing FTTC and to effectively compete with competitors such as Virgin Media and Siro.

Siro deployment

In May 2015, Siro launched and commenced the rollout of their FTTH networks in 50 regional towns passing close to 500,000 premises. To date, Siro has passed about 150,000 premises.

Siro's deployment is based on GPON. However, in December 2017, Siro announced the successful trial of XGS-PON technology and have also indicated that XGS-PON is part of their future roadmap.

e|net deployment plans

e|net have announced the rollout of an FTTH network in 9 towns in the west of Ireland. At this point, it not clear to us what technology will be used and what progress has been made.

4.4 Rationale for adoption of NG-PONs

Operators have cited varied reasons for the upgrades. These are as follows:

- Keeping up with other kinds of broadband infrastructure (cable, 5G fixed wireless);
- Readiness for future consumer service demand;
- Symmetrical multi-gigabit business connectivity;
- Reduction in fibre infrastructure;
- Wireline backhaul and;
- Readiness for cell densification and 5G.

The above reasons are not all relevant to all operators but may be relevant to Irish operators and may consequently indirectly impact the NBP which aspires to ensure that there is no "digital divide" between urban and rural users.

We explain in detail below the different drivers for different operators worldwide to deploy NG-PON.

Keeping up with other kinds of broadband infrastructure (cable, 5G fixed wireless)

This is in effect the preservation of marketing advantage in competitive environments. Not all FTTH operators will face challenges from other technologies, and some may face challenges only from other FTTH plays. In these cases, NG-PONs give a rather short-lived competitive advantage. For example, in Singapore[31], all three main operators launched 10Gbit/s within months of one another.

FTTH is not uniquely able to supply gigabit access, although the successor technologies to GPON are standardised technologies with higher specs than any of the following alternatives.

- Cable network-based DOCSIS3.1 has a number of variants, and can supply gigabit downlinks, and in future variants significantly more. It is generally more limited in uplink, although DTA

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[31] Singapore market is very different from most European market as it is more competitive, mainly due to the high population density

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modifications means it could supply, dynamically, 1Gbit/s uplink. Shared symmetrical bandwidth of 10Gbit/s is theoretically possible (i.e. the same as XGS-PON), though no cable operator is as yet close to offering this. Most commercial cable operators have either started to deploy some variant of DOCSIS3.1 or have plans to do so in the next 12-24 months.

- G.fast Amendment 3 can, over distances of up to about 100m, supply 1Gbit/s downlink on a single copper pair. This variant is suitable mostly for multi-dwelling units. Commercial interest in lower-speed, longer-loop variants of G.fast appears to be diminishing.

- mmWave fixed wireless access, whether based on 5G standards or not, is an emerging technology alternative that has not as yet been commercially deployed, though Verizon expects to do so in some cities in the USA as early as 4Q 2018. Trials indicate that under the right conditions, 1Gbit/s per user should be achievable, although there remain question-marks over reliability, performance, range and cost. mmWave fixed access is being trialled in various environments. As with other forms of fixed broadband, costs rise as premises density falls. Early indications are that it will be used predominantly as a challenger technology in urban areas. This stands in contrast to current 4G fixed wireless services, which have been focused on rural areas.

Not all FTTH operators will face all of these challenges. Where they do face these challenges, they will have at their disposal NG-PONs, standardised technologies with higher specs than any of the non-fibre alternatives.

Readiness for future consumer service ecosystem

Busy-hour consumer fixed bandwidth demand is growing at about 40–50% per annum in developed economies[32]. This is faster than wireline data growth (about 30%-35%) because diurnal data traffic patterns are becoming peakier. However, this is an aggregate view, and may show simply that more households are streaming high-resolution video at peak hours rather than show a demand for more bandwidth per household.

It makes sense to separate trends in consumer bandwidth into:

- The maximum speeds that operators feel they need to offer to remain competitive. This is typically in Europe 1Gbit/s downlink; in many developed Asia-Pacific countries it is already 10Gbit/s. The CAGR of peak offers everywhere has historically been about 55-60%, although growth is staggered. Note in this respect that the Swiss mobile operator Salt entered the fibre broadband market in March 2018 with a 10Gbit/s symmetrical broadband service retailing at less than half of the price of competitors' 1Gbit/s services.
- The downlink speeds below which usage, measured in gigabytes per month, is constrained; this is sometimes referred to as 'comfort speed'. This is in part conditioned by supply. In much of Europe we estimate this to be currently about 50-60Mbit/s, but in a market such as Singapore,

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[32] Fixed Network Data Traffic: worldwide trends and forecasts 2017-2023, Analysys Mason (December 2017) http://www.analysysmason.com/Research/Content/Reports/fixed-network-data-RDNT0/

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where the lowest-speed fixed access available is now 300Mbit/s, it has to be higher. We estimate CAGR to be about 40-45%.

Hence we estimate there is an 8-10 year gap between the two: i.e. the peak speed today will be the comfort speed in 8-10 years' time.

Figure 4.2: Maximum marketed and comfort consumer broadband downlink speed for typical W European market [Source: Analysys Mason, 2018]
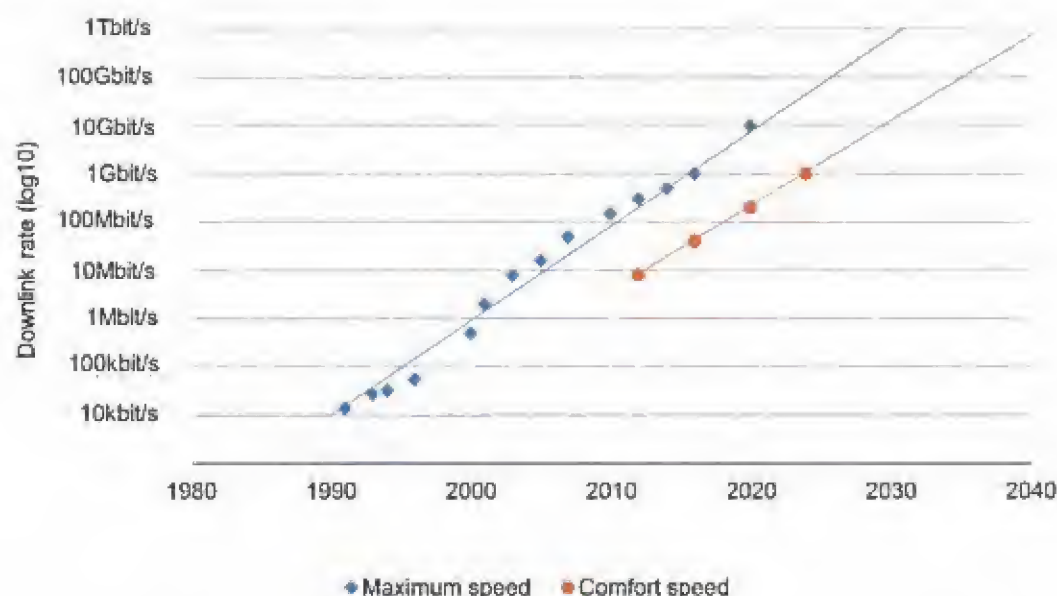
By this measure, and assuming a continuation of trends, 1Gbit/s downlink, will be a comfort speed in the mid 2020's. It seems highly likely that by the mid-2020s most operators in developed economies will be selling multi-gigabit Internet access to most consumers. So long as trends continue at the same pace, 10Gbit/s will be the comfort speed in about 2032. If unit costs for NG-PONs fall fast, then the growth rate of maximum speeds could accelerate, effectively creating significant capex avoidance. One of Verizon's main arguments in favour of TWDM-PON over XGS-PON is simply that the additional bandwidth buys them more time.

New video formats (e.g. 4K) and future formats (e.g. 8K) stimulate demand for higher bandwidths, but they are probably not sufficient to justify NG-PONs. 4K with a high frame refresh rate such as that already used for BT Sport 4K UHD requires a minimum speed of 44Mbit/s. An extreme case of 100% simultaneous usage on a 32-split GPON at a peak viewing time (say for a major sporting event) would consume just over half of the available bandwidth. Filling GPON capacity with video seems like a long way off. It seems unlikely that flat screen video has much further to go than 8K; differences may be imperceptible, and screen-size may be impractical. VR (especially when tactile) may create a profound change in requirements not only for consumer bandwidth but also for ultra-low latency. One can only speculate on the supply and take-up of such services. However, as the capital-intensive heavy-lifting of passive FTTH deployment is completed, the long-term inhibitor of

application development for ultrafast broadband, lack of infrastructure (and the cost of optimising services to adapt to that shortfall), will weakening.

Considering demand in terms only of future real-time services misses some of the utility of multi-gigabit broadband to the end-user, utility that can be experienced right now. The value of the bandwidth lies not in a high number of simultaneous ultra-high definition video streams but in near-instantaneous upload and download. A typical 4K game for example is about 50 gigabytes; a download on a 50Mbits/ connection would take 2 hours 13 minutes, on 1Gbit/s connection 6 minutes 40 seconds, and on a 10Gbit/s connection just 40 seconds. There is no reason to believe that the size of games – or of other files – will stand still. Marketing for those consumer multi-gigabit services that already exist tends to emphasise file transfer speeds rather than applications. For real-time services it is difficult to see any current or future value in 1Gbit/s uplink, let alone 10Gbit/s; for non-real-time the value of it for near-instantaneous delivery is much clearer.

Symmetrical multi-gigabit business connectivity

While some operators cite this as a reason to upgrade, and like M1 in Singapore offered B2B services ahead of B2C, each PON will pass only a limited number of business sites[33] likely to be interested in multi-gigabit connectivity, and business demand for bandwidth can be overstated. Business broadband connections consume on average under half the data of residential connections, where usage is more dominated by video.

TWDM-PON, and XGS-PON when overlaid on an existing GPON, allow a dedicated connection to be run over a separate wavelength from consumer broadband. Some operators deploying NG-PONs including Verizon have cited the opex benefits of offering enterprise leased lines and consumer broadband on the same optical distribution network.

Reduction in fibre infrastructure

XGS-PON provides 4 times as much downlink bandwidth as GPON. This means that if an operator wanted to provide 100 Mbit/s broadband services to its end-users, it could deploy XGS-PON using 128 splits instead of using GPON with 32 splits. Since more end-users would be served by each PON network, less fibre[34] and fewer OLTs would be needed in the network, potentially saving capex and/or opex for new build.

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[33] especially in rural Ireland

[34] In the section of the network located between the OLT and the splitter, where a single fibre is shared between all PON end-users.

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Wireline backhaul

Operators such as EneCom in Japan are already deploying next-generation PONs for backhauling G.fast. The case is best for FTTB to large multi-dwelling units (MDUs). We would expect XGS-PON and TWDM-PON to become a common element in both the access and the aggregation layers of many larger integrated operators with a fixed access technology mix, for example AT&T, Verizon and SK Telecom. Some vendors are integrating fixed-wireless termination options into PONs.

Readiness for cell densification and 5G

5G-readiness is frequently cited as a need. 5G may in the future require a much greater density of cell infrastructure than is currently the case for 4G, although we do not expect this to be the case for early deployments of 5G in Europe. Greater cell density is unlikely to be required at all outside urban areas (including the areas addressed by the NBP) and major transport routes. Where it is required, sharing the infrastructure costs between fixed broadband and mobile backhaul makes economic sense. If overlaid on a GPON, the separate NG-PON wavelengths can serve as dedicated mobile backhaul without being affected by traffic on the GPON wavelengths.

Some mobile operators are beginning to shift to virtualised radio access networks, where some or all processing of signal is carried out centrally rather than at the radio site. This could potentially save operators capex and opex, making networks more efficient and responsive, but the links to the centralised Base Band Units (BBUs) require much greater bandwidth and lower latency than traditional backhaul, where the signal is processed at the local BBU before hitting the backhaul network. There are a number of variants in fronthaul transport proposed, some more demanding in terms of bandwidth. The very high bandwidths on NG-PON wavelengths could carry some of the less demanding variants more cost-effectively and with acceptable QoS than the technologies used for traditional backhaul links. However, even 10Gbit/s may not be sufficient for some foreseeable 5G variants. One of the main drivers of research into 25GPONs and 100GPONs is their perceived suitability for these very demanding but non-customer-facing functions.

Combinations of the above.

All of the above are potential use-cases; not all will be applicable everywhere. What XGS-PON, when overlaid on GPON, and TWDM-PON offer, though, is the ability to maximise the monetisable value of the underlying passive network, and in doing so achieve significant long-term capex and opex avoidance. The optical distribution network thereby becomes a largely one-off cost with multiple functions. In this sense, PON is evolving from a fixed broadband technology to the all-encompassing full-service network that the FSAN group envisages.

The additional use cases beyond consumer and SME broadband are unlikely to apply to any significant extent outside urban areas. Arguably though, the consumer utility use-case is the most compelling, and this can apply anywhere.

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4.5 Conclusions

A number of operators worldwide have already deployed NG-PON technology overlay for different reasons:

- Large incumbent such as China Telecom, China Mobile, KDDI and AT&T[35] have all deployed XGS-PON overlays.
- Verizon, who has longer-term capex and opex avoidance aims, and who places greater emphasis on enterprise and mobile transport opportunities, have deployed the less mature but higher specification TWDM-PON.
- Altice, itself a vendor of PON equipment, is committed to TWDM-PON overlay as a replacement for cable in the USA. Altice also supplies its subsidiary operator businesses in Portugal and France.
- Very few operators have launched NG-PON at scale in Europe other than Salt in Switzerland, who entered the broadband market in March 2018 with a 10Gbit/s symmetrical broadband service retailing at less than half of the price of competitors' 1Gbit/s services.

In Ireland, open eir and Siro are both deploying GPON-based FTTH networks, and it is anticipated that, due to increasing competition between themselves and with Virgin Media, NG-PON overlay will be deployed within the next 3 years in Ireland. Siro have already signalled that it has successfully trialled XGS-PON in December 2017, in partnership with Huawei. Eir's new owners have indicated that they will focus on urban areas. In order to differentiate themselves from Virgin Media and Siro they may also consider XGS-PON.

Other key drivers pushing operators to deploy NG-PON networks include providing symmetrical multi-gigabit business connectivity, providing backhaul for wireline broadband networks as well as providing backhaul and fronthaul connectivity services for cell densification and 5G

It seems likely that by the end of the 2020s, 1Gbit/s services will be sold to some consumers and small businesses, and that in regions with competitive telecoms many, perhaps most, operators will also sell multi-gigabit access. However, any operator going straight to any form of NG-PON now would have carefully to balance the higher up-front active equipment costs now against the longer asset-life of a higher-capacity network.

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[35] Due to launch is Q1 2018

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5 Suitability of XGS-PON for the NBP and future proofness

5.1 Introduction

In embarking on the National Broadband Plan, the main objective of the Irish Government is to provide a high-speed broadband service that delivers download speeds of at least 30 Mbit/s and minimum upload speeds of 6 Mbit/s for 100% of the Irish population. To meet this objective, the Government is planning to include the following requirements in its contract with NBPco:

Requirement 1 – NBPco is obliged provide the following set of "minimum Required Wholesale Products":

- Minimum Bitstream Wholesale Product
- Minimum Virtual Unbundled Access (VUA) Wholesale Product
- Duct Access Product;
- Pole Access Product;
- Unbundled Fibre Access Product;
- Dark Fibre Product;
- Radio Tower and Mast Access Product
- InterConnect Product;
- Transmission Product;
- Building and Cabin Co-Location Product.

Requirement 2 – NBPco is also obliged to provide "Additional Required Wholesale Services" with the following characteristics:

- Business Wholesale Products which are equivalent to residential Wholesale Products but with enhanced Operational KPIs;
- Any other Wholesale Products that, for example, may be suitable for Strategic Connection Points; and
- Any other variants of residential Active Wholesale Products that are not Minimum Required Wholesale Products.

Requirement 3 – NBPco may also elect to provide "Other Permitted Wholesale Products"[36] including mobile backhaul and leased lines if NBPco can demonstrate that they do not distort the market for these products.

Requirement 4 – NBPco is obliged to deliver Wholesale High Speed Broadband Products in the IA that are of broadly equivalent in performance to Wholesale High Speed Broadband Products in the commercial area throughout the contract duration.

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[36] to improve its business case and therefore lower the required subsidy

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Requirement 5 –NBPco is obliged to ensure that its Network and associated operational solution are future proof and are able to evolve to provide future enhanced Wholesale Products or New Wholesale Products throughout the contract duration.

5.2 Assessment of XGS-PON suitability against NBP requirements

We assess the relative merits of XGS-PON against the main NBP requirements below

XGS-PON will enable NBPco not only to meet but also to exceed the Government objective in terms of broadband speed for all active "Minimum Required Wholesale Products", including Bitstream and VUA (Requirement 1)

The government objective is to provide high-speed broadband service that delivers download speeds of at least 30 Mbit/s and minimum upload speeds of 6 Mbit/s for 100% of the Irish population. Based on the spread of premises in the Intervention Area and our previous modelling work, we believe that on average, 16 end-users will be connected to every PON (corresponding to a 50% PON occupancy with a 1:32 split). In an XGS-PON, this means that the 10Gbit/s symmetrical bandwidth will be shared between 16 end users, guaranteeing a 625 Mbit/s to each user anytime. Since not all users will use the broadband network at the same time and that statistical multiplexing will take place, we are confident that XGS-PON can support well in excess of 1Gbit/s of symmetrical bandwidth per end-users. This is more than 30 times the 30 Mbit/s of download speed and more than 150 times the 6 Mbit/s of upload speed required by the Government. Therefore XGS-PON as a technology will be able to significantly exceed the government objectives (from day 1) and will have the ability to provide Bitstream and VUA Wholesale Product with enough capacity for residential end-users for most of the next decade, making the technology future proof.

Also, as demonstrated in the previous section, XGS-PON is starting to get significant traction worldwide for different reasons and we expect it to represent the bulk of FTTH operator's investment worldwide in GPON by the mid 2020's.

Fibre Unbundling Products could be provided by means of TWDM-PON overlays from Service Providers on NBPco PON network, but the economics is unlikely to work in rural Ireland. (Requirement 1)

TWDM-PON is today the most appropriate PON technology able to deliver virtual fibre unbundling services in point to multi-point networks. This is because different RSPs can each have a dedicated PON network serving their own customers on a different wavelength as explained in Section 3.5. However, as demonstrated in Section 3.4.4, the significant premium cost associated with TWDM-PON today does not make it feasible (from a cost perspective) to provide unbundled fibre wholesale products.

Instead, XGS-PON+ will include some form of "network slicing" which will enable Wholesalers to logically partition their networks and allocate appropriate resources to different RSPs. Although

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network slicing will result more in a managed service rather than a Fibre Unbundling service, it will be significantly more cost effective for NBPco to deploy unbundled fibre services using the network slices, which will be available through a software upgrade of the XGS-PON system.

XGS-PON will be particularly suitable to provide services to businesses and Strategic Connection Points **(Requirement 2)**

As described in Section 4.3 of this paper, business services are often cited as a key driver for operators to deploy XGS-PON. Since NBPco is required to provide Wholesale Products to both businesses and Strategic Connection Points, XGS-PON will be particularly suited as a technology to be deployed by NBPco. This is because businesses are likely to require more upload capacity than residential customers.

XGS-PON will be particularly suited to provide Other Permitted Wholesale Products such as mobile backhaul and Leased lines **(Requirement 3)**

As described in Section 4.3 of this paper, 4G and 5G backhaul and fronthaul is a key application driving the adoption of XGS-PON. This is exemplified by the fact that FSAN/ITU standardisation body is currently formally specifying of 5G Fronthaul[37] requirements in a PON context as part of the XG(S)-PON+/NG-PON2+ roadmap. In the NBP, 4G and 5G mobile backhaul may represent a significant source of revenues and the selection of XGS-PON technology by NBPco would be a key enabler.

Leased lines are high speed symmetrical connectivity services, usually provided to medium businesses, large corporate and public-sector clients. The symmetrical nature and high capacity of XGS-PON would facilitate to deployment of leased lines and would therefore enhance NBP Co business case, reducing the required subsidy.

XGS-PON should enable NBPco to provide Wholesale Products with similar characteristics to those provided in commercial area until late 2020's **(Requirement 4)**

As mentioned in previous sections, Eir and Siro have both deployed GPON technology in commercial areas. It is expected that if NBPco deploys XGS-PON in the Intervention Area from 2019, they will effectively be one GPON generation ahead of commercial areas and therefore will be in a position not only to replicate but to exceed the characteristics of wholesale Products proposed in commercial areas in the short to medium term.

Siro successfully trialled XGS-PON in Dec 2017[38] XGS-PON and may deploy this technology to gain a competitive advantage as an overlay network in areas where it can be justified (where there is strong competition). Following, the majority stake acquisition of eir by NJJ Telecom and Iliad,

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[37] Fronthaul is usually defined as the network connecting Remote Antennas of 5G systems back to the processing Baseband Broadband units.

[38] https://siro.ie/huawei-trial/

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eir has signalled that "it will now put a greater emphasis on developing state-of-the-art services in key urban locations". This may drive eir to deploy next generation PON technology (e.g. either XGS-PON or TWDM-PON) to compete with other high-speed broadband networks such as Siro's FTTH network and Virgin Media cable network offering broadband speeds of up to 350 Mbit/s through the use of DOCSIS 3.1 technology.

Based on the above observations, it is likely that Next Generation PON (i.e. XGS-PON or NG-PON2) will start being deployed in Ireland within the next three years (i.e. before the end of 2021) and may become a mainstream technology in commercial areas to offer high speed broadband services by the mid 2020's. If NBPco was to deploy XGS-PON from 2019, it would, from a technology perspective, be able to track Wholesale Products at least until the late 2020's.

Physical PON infrastructure will provide a future proof platform and NBPCo will have an upgrade path in terms of technology till the end of the contract (Requirement 5)

It is anticipated that active equipment (including GPON OLT and ONTs) will represent less than ▮ of the capital expenditure for the NBP Network. The optical distribution network (ODN) is largely a one off capex, and based on the all-encompassing full-service network vision of the FSAN group, the real future proofness is in the ODN itself and not the actual overlay technology. Standards for the different NG-PON overlay networks has been defined with this vision in mind in such a way that, when a higher specification system is required, it can be deployed alongside existing legacy (N)G-PON technology on the same physical PON network.

Beyond XGS-PON estimated lifetime (late 2020's), another, higher specifications NG-PON technology will need to be deployed as an overlay network to continue tracking wholesale products in commercial areas and cater for the increase in bandwidth demand. We do not anticipate this to be a significant issue.

5.3 Conclusion

Based on the Government objectives associated with the NBP, we believe that:

- XGS-PON will enable NBPco not only to meet but also to exceed the Government objective in terms of broadband speed for all active "Minimum Required Wholesale Products", including bitstream and VUA.
- Fibre Unbundling Products could be provided by means of TWDM-PON overlays from Service Providers on an NBPco PON network, but the economics would appear challenging in rural Ireland.
- XGS-PON may be able to provide some form of Fibre Unbundling in the medium term through network slicing technology.
- Considering its symmetrical profile, XGS-PON will be particularly suitable to provide services to businesses and Strategic Connection Points.
- XGS-PON should enable NBPco to provide Wholesale Products with similar characteristics to those provided in commercial area at least until the late 2020's.

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- PON will provide a future proof platform and NBPCo will have an upgrade path in terms of technology till the end of the contract.

Although XGS-PON attracts a cost premium compared to GPON today, using XGS-PON will not significantly impact the cost per premises to pass[39] and will only increase the cost to connect by ▮▮▮ ▮▮▮▮ if XGS-PON costs were to remain as they are today. However, as discussed in section 3 4.4, as XGS-PON volumes increase, we expect XGS-PON costs to continue falling in the foreseeable future which will partially compensate for the initial premium to pay for premises which will be connected in the initial years of the NBP deployment. Also, deploying XGS-PON straight at the beginning of the contract period will enable NBPco to refresh active at a much later stage than if GPON was to be deployed (i.e. refreshment in late 2020's with XGS-PON instead of the mid 2020's for GPON), which will lead to capex avoidance, a reason which has been put forward by Verizon to deploy NG-PON2 technology.

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[38] We consider OLT costs as cost to pass in our Budget model

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